Stochastic Cooling for RHIC

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Acknowledgements

Mike Brennan, Freddy Severino, Beam components and RF groups (BNL)

Dave McGinnis, Ralph Pasquinelli (FNAL)

Flemming Pedersen, Fritz Caspers (CERN)

Alejandro Luque, Hans Schamel (University of Bayreuth)

- History
- RF activity
- The RHIC System

History

Herr and Mohl reported cooling bunched beams in ICE (1978)

Chattophadyhay develops bunched beam cooling theory (1983)

$$\theta - \omega_0 t = \varphi(t) \approx a \sin[\omega_s(a)t + \psi_0]$$

Stochastic cooling considered for SPS, RHIC and Tevatron (80s).

Unexpected RF activity swamps the Schottky signal (85s).

Cooling rate scales as 1/N, Z=79 for Au so N is small

Cooling of long bunches in FNAL recycler.

RF Activity (anomalous high frequency power)

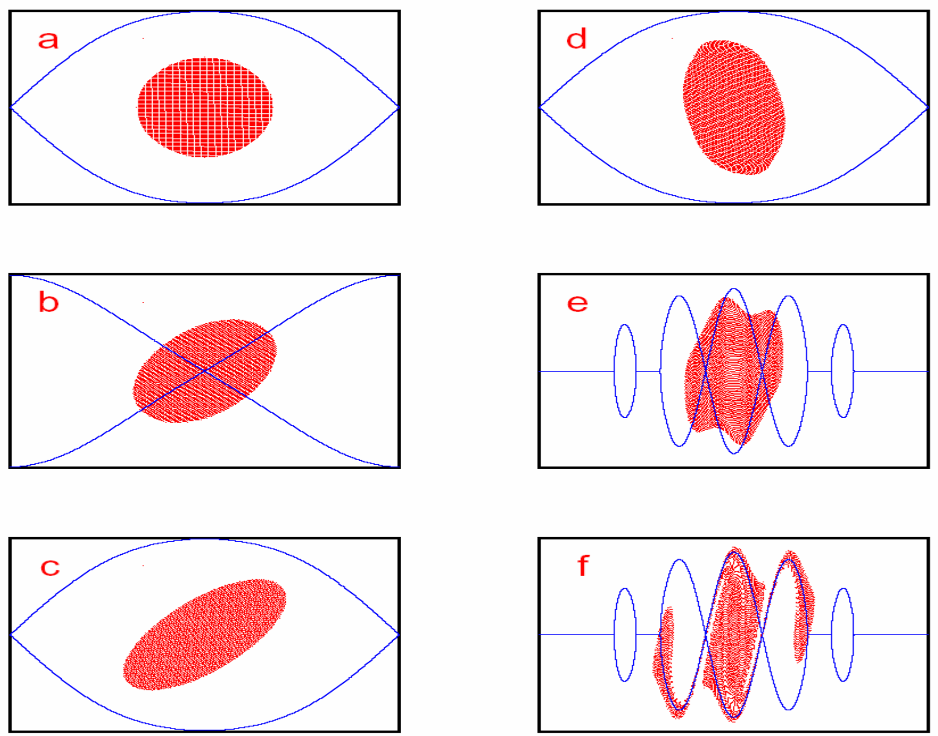
Two distinct types:

1) Strong revolution lines
2) Strong signals associated with synchrotron motion

We see the first type with heavy ions and both with protons.

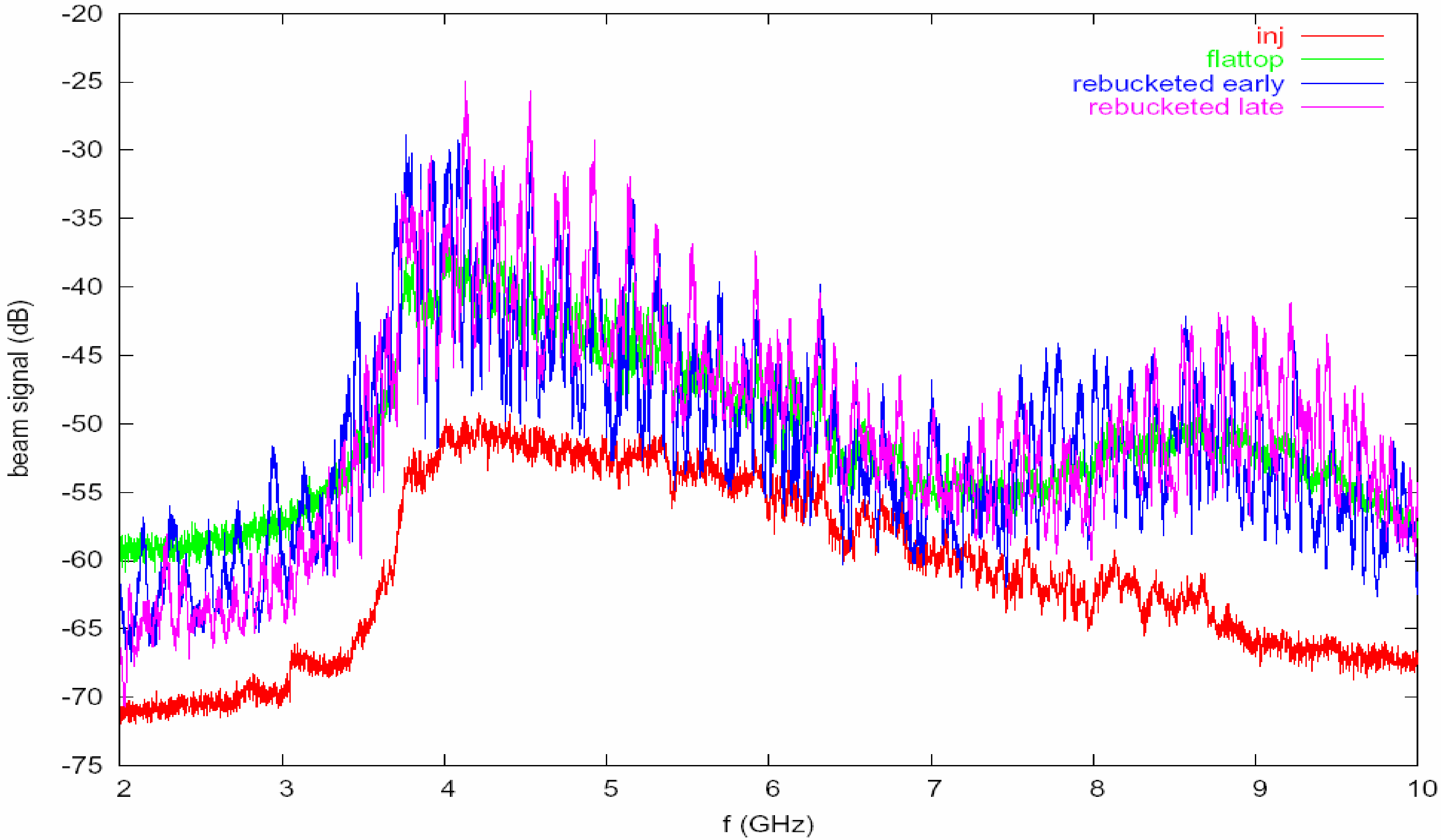
Heavy ions are “rebucketed” to shorten the bunch and combat IBS.

Precooling might be required.



Wide band copper spectra

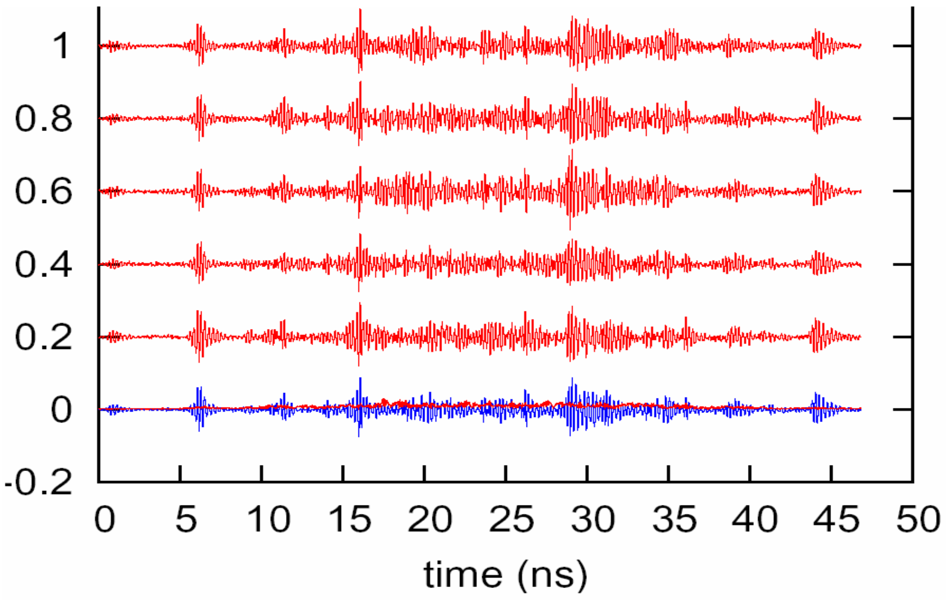
Coherent signals begin at rebucketing and persist for hours. (Saturation present)



Time domain signals
from different Cu bunches

$$S_1(t) = \sum_{k=0}^{3} S_0(t - k \times 5ns)$$

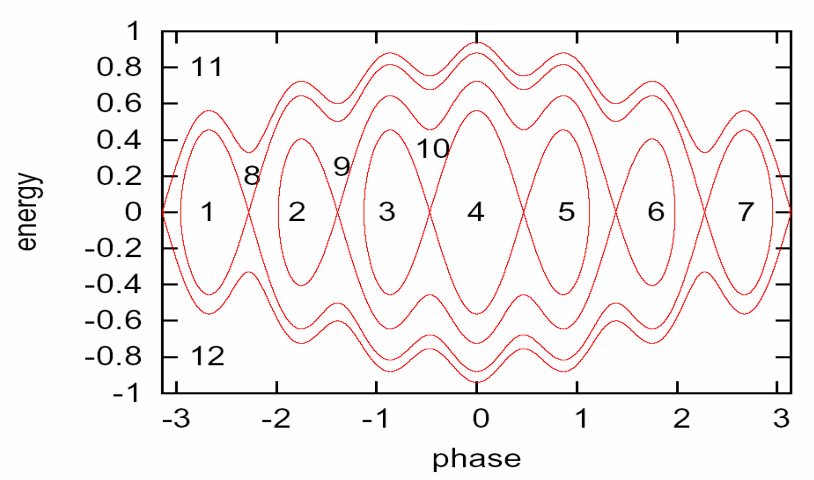
Blue is average, which is filtered out. Orange is rms Schottky. Thanks Agilent!



Separatricies for
Storage bucket

$$P_k(H) = \int_{regionk} dpd\phi\Psi(p,\phi,t)\delta[H - p^2/2 - U(\phi)]. \quad (1)$$

$$\Psi_k(p,\phi) = P_k[H(p,\phi)]/T_k[H(p,\phi)]$$



Protons show evidence of forced oscillations

- 40 Hz phase noise
- source remains elusive
- Simulations show discontinuity in stroboscopically averaged phase space density.
- Density discontinuities create broad band power.

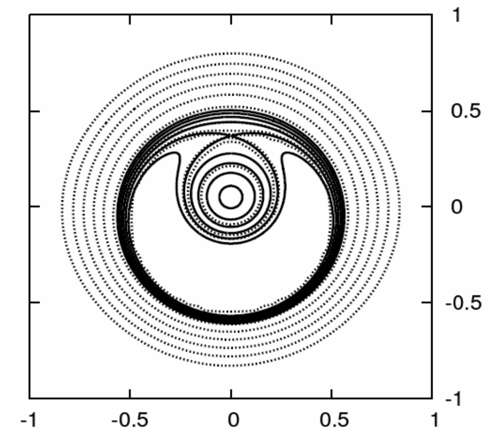


FIGURE 3. Contour plots for the stroboscopic average of the simulated phase space density (dashed lines) and for the approximate Hamiltonian (solid line). The parameters were $\nu = 0.99$ and $\alpha = 0.001$ with the intital, matched bunch confined to $|\phi| < 1$.

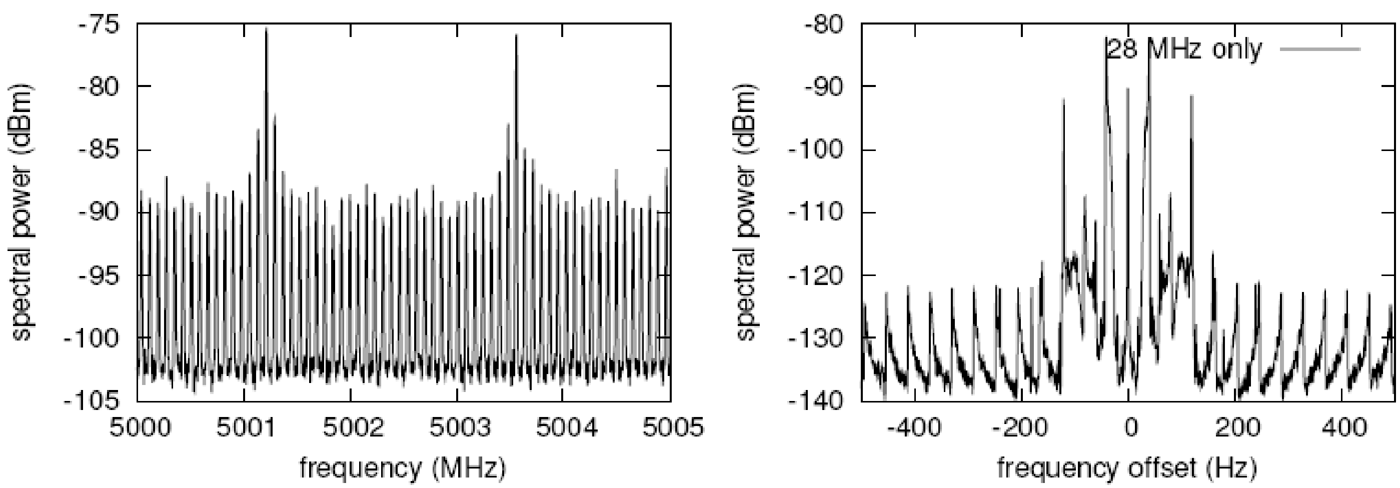


FIGURE 2. High frequency signals for 28 proton bunches in a 30 bunch fill pattern. The broad band signals (left panel, A) exhibit the 2.36 MHz bunching frequency. A narrow band signal centered on the strong right peak is shown in the right panel (B).

Filter for Halo Cooling

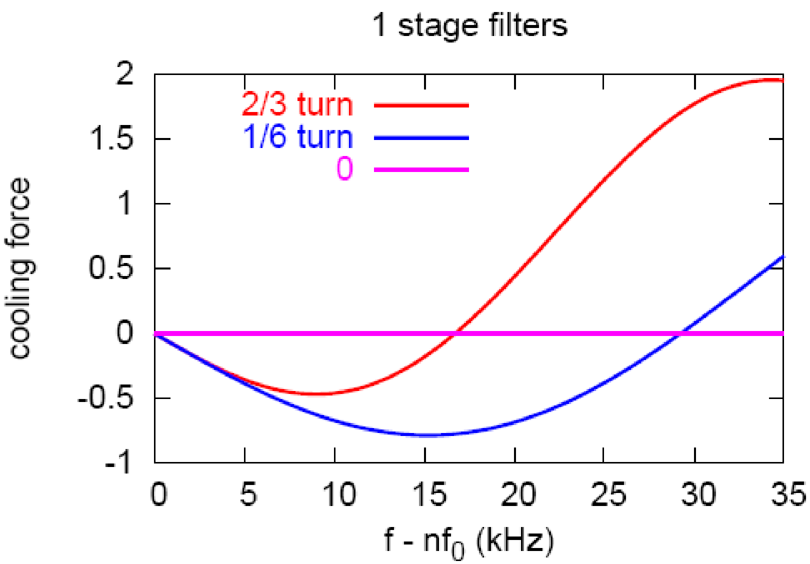
For cooling we need a force that reduces the energy error.

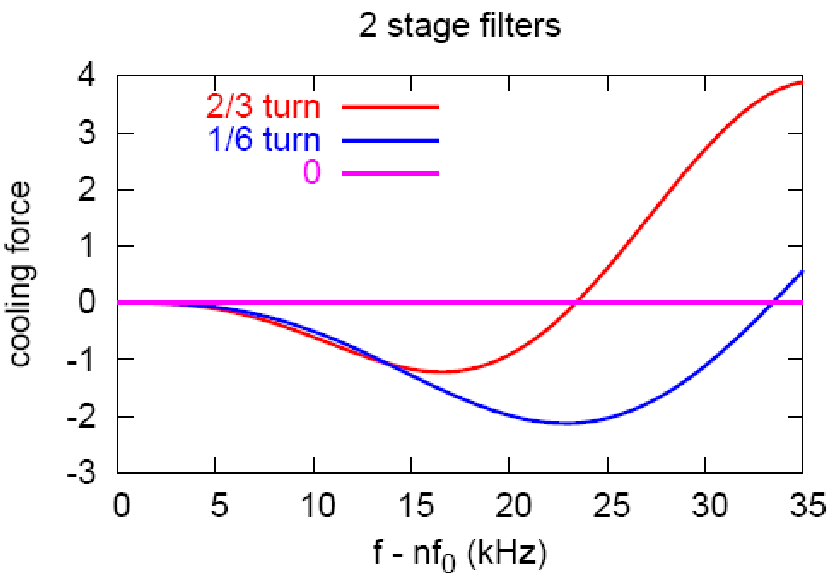
Filter cooling does not require a special lattice.

Yellow delay is 2/3 of a turn so we can run fiber-optic in the tunnel.

Blue will use a microwave link for 1/6th turn delay

$$S(\omega) = G[1 - \exp(i\Delta\omega T_{rev})]^n \exp(i\Delta\omega T_{delay})$$





Signal Suppression

current at pickup due to voltage at kicker

$$I_1(\tilde{\omega}) = B(\tilde{\omega})V_K(\tilde{\omega}) \propto qN$$

total current at pickup

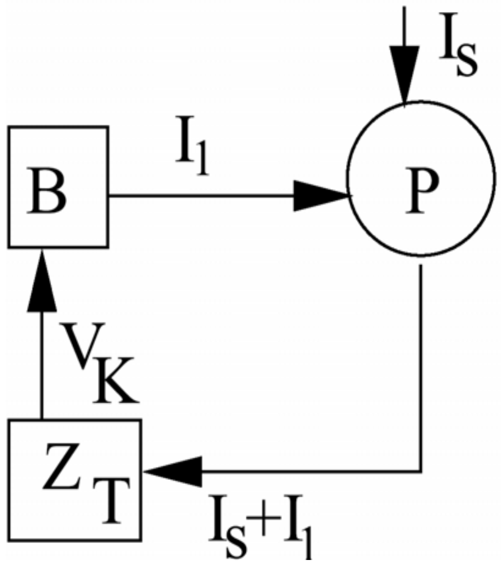
$$I_P = I_1 + I_S, \qquad I_S \propto q\sqrt{N}$$

voltage at kicker due to current at pickup

$$\begin{aligned} V_K &= -I_P Z_T \\ &= -(I_1 + I_S)Z_T \\ &= -BV_K Z_T - I_S Z_T \end{aligned}$$

net voltage at kicker due to Schottky current

$$V_K = \frac{-I_S Z_T}{1 + BZ_T} \equiv -Z_D I_S$$



Ip is suppressed by the same factor.

Optimal cooling gain for

$$BZ_T \approx 1$$

Coasting beam cooling rates

Did coasting beam cooling rate calculations based on peak beam current, Amps.

Au, 100 GeV/A

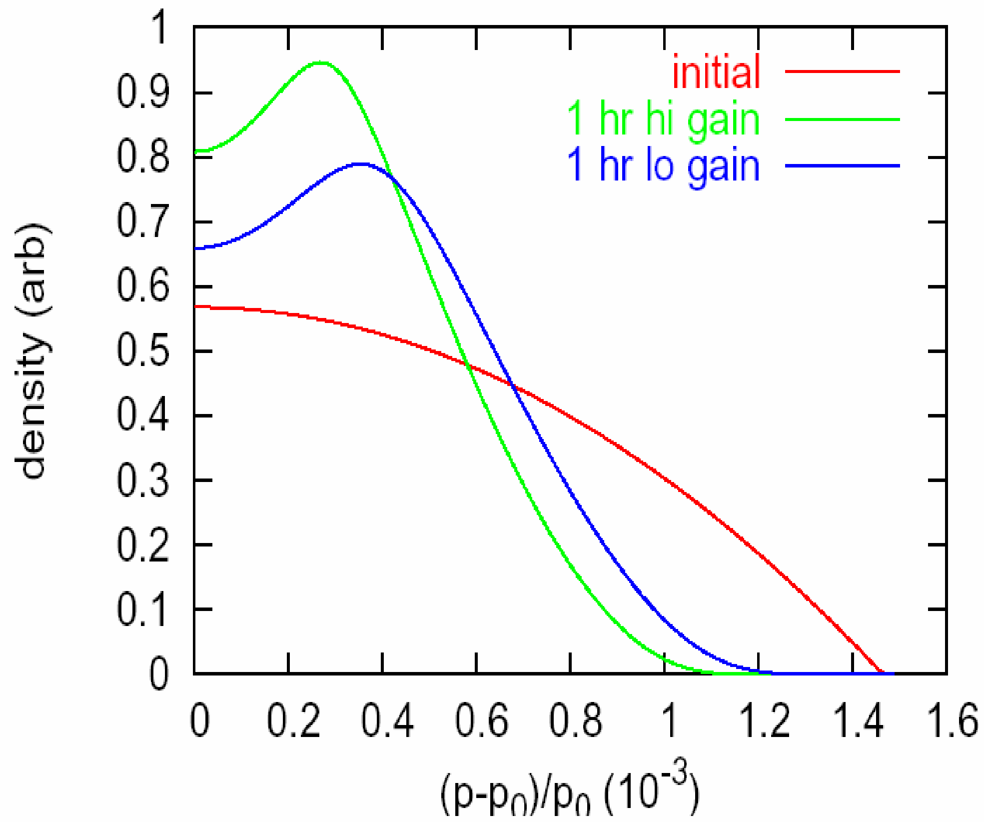
Vs=4MV, Va=0.

2/3rd turn, IBS was included.

$$\frac{\partial \Psi}{\partial t} = \frac{\partial}{\partial \omega}\left[-F(\omega)\Psi(\omega,t) + D(\omega,t)\frac{\partial \Psi}{\partial \omega}\right]$$

A few kV of cooling voltage was required.

Agrees with other simulations (Jie Wei) and order of magnitude estimates (Mike Brennan +)



Voltage considerations

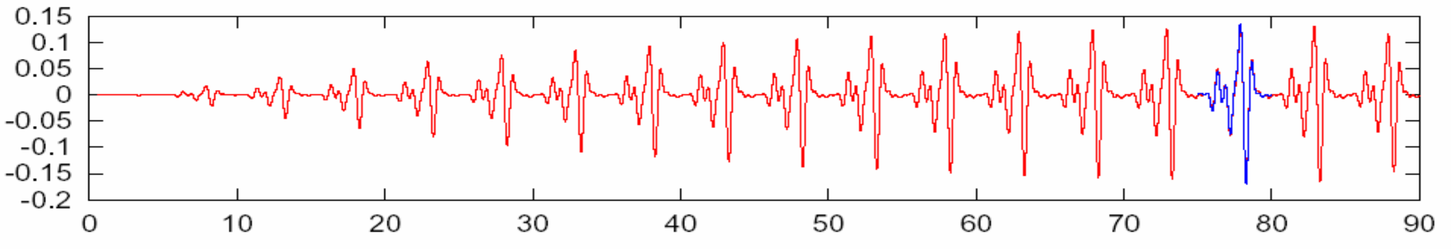
For 5-8 GHz need 3.6 kV rms, large by stochastic cooling standards

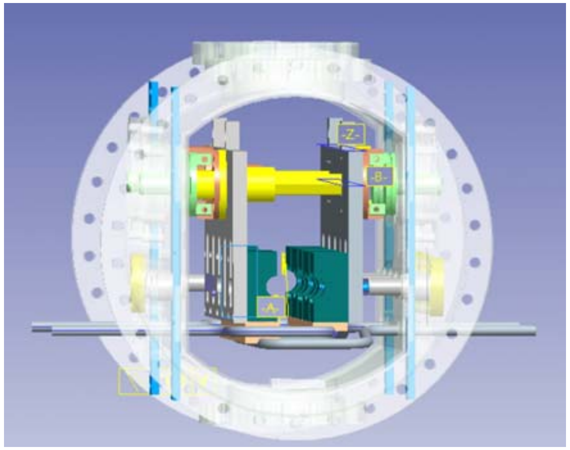
Bandwidth-Voltage product sets the cost scale

Bunches are $\tau_b = 5ns$ long, and spaced by $T_b = 100ns$

The value of the kicker voltage matters only when the bunch is present.

$V(t) = \sum_n A_n \sin(2\pi nt/\tau_b + \theta_n)$ A_n and θ_n vary smoothly





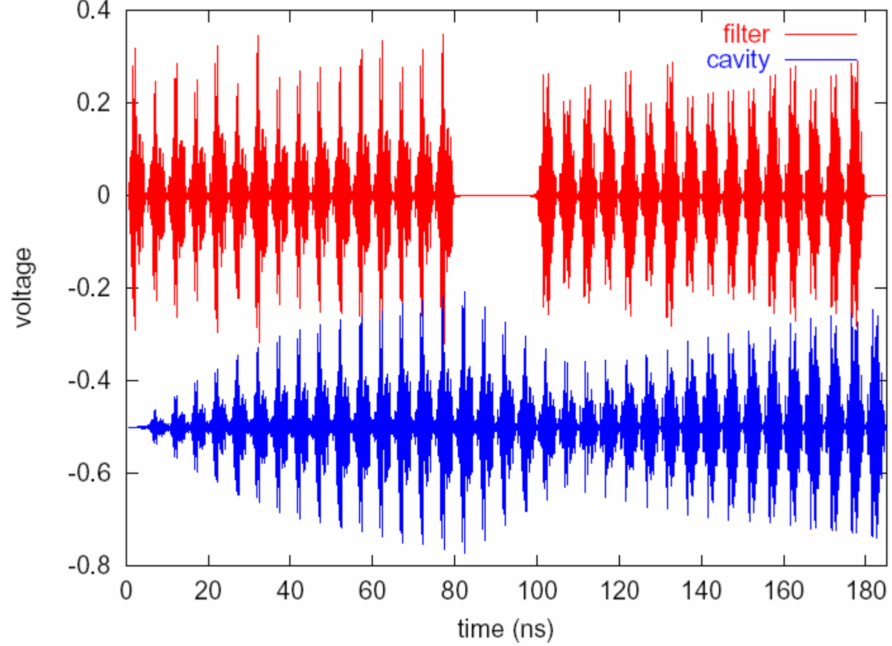
Error Limit Simulations

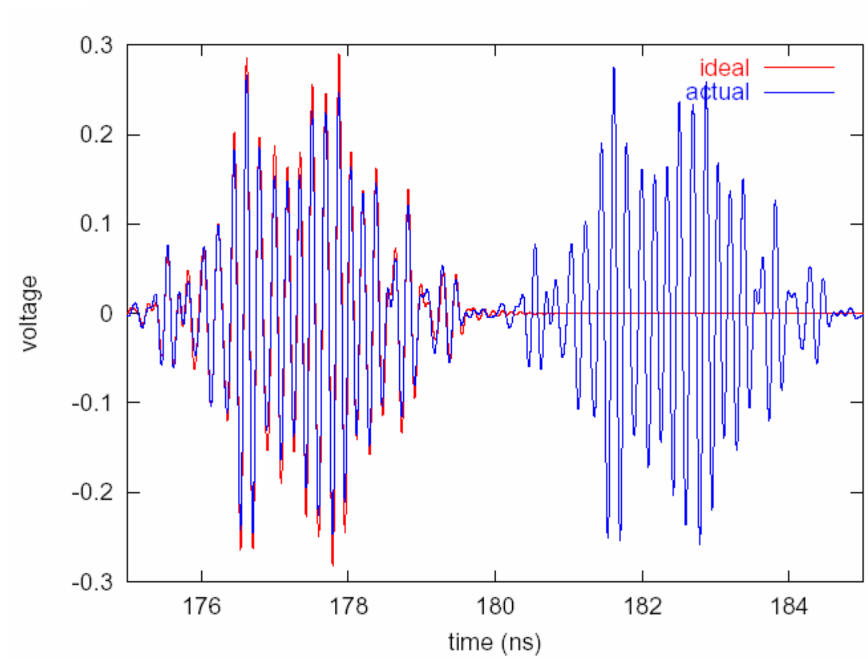
Took conservative errors.

- 2 ps timing error
- 20% amplitude errors
- 2 MHz cavity frequency errors

Desired cooling voltage is modeled as band limited noise.

System is well behaved with these errors.





Voltage and Power continued

Take 16 cavities, 5-8 GHz bandwidth 40 Watts/cavity (10 K each)

R/Q=100Ω, 10 MHz FWHP bandwidth, R ≥ 50 kilo-Ohm

gives 1 to 1.4 kV rms per cavity, or 5.6 kV total

Cavity drive signal needs to be roughly sinusoidal for R (not R/Q) to matter

Suppose $S_0(t)$ is the drive signal for a broad band kicker (like a resistor).

Periodically extend $$S(t) = \sum_{k=0}^{N-1} S_0(t - k\tau_b)$$

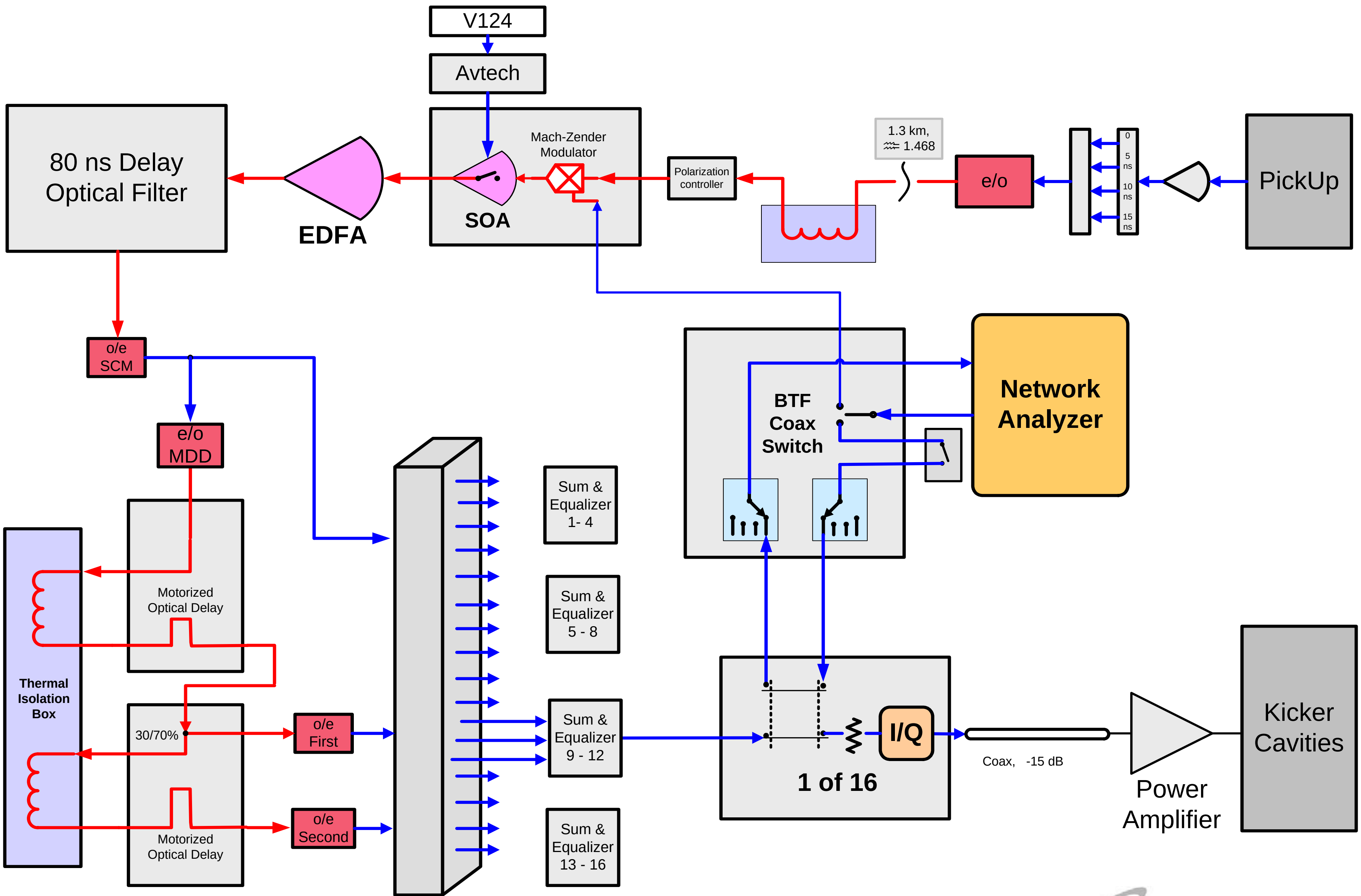
This creates a signal with 10 MHz $(1/T_b)$ wide peaks,

spaced by 200 MHz $(1/\tau_b)$

Split and pass through 100 MHz filters, centered on cavity resonance, before power amps. In this way each amplifier sees a piecewise sinusoidal input.

Combination of transmission lines and fiber optic technology for the delay line (traversal) filter.

Stochastic Cooling Low Level Block Diagram



Two stage filter signal suppression

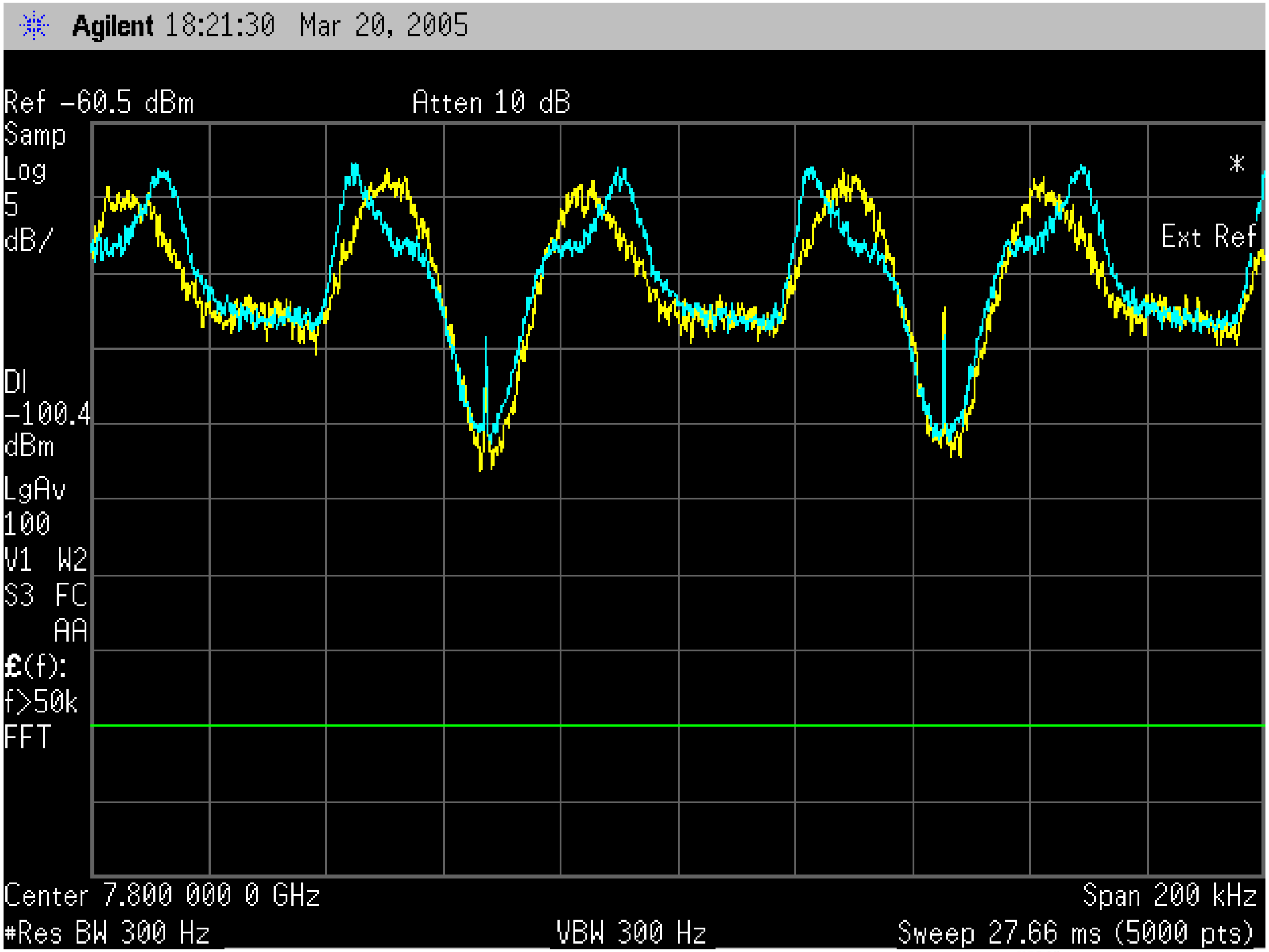
Cu

Va=300kV

Vs=1.3MV

E=30GeV/A

Frequency spread is too big here.



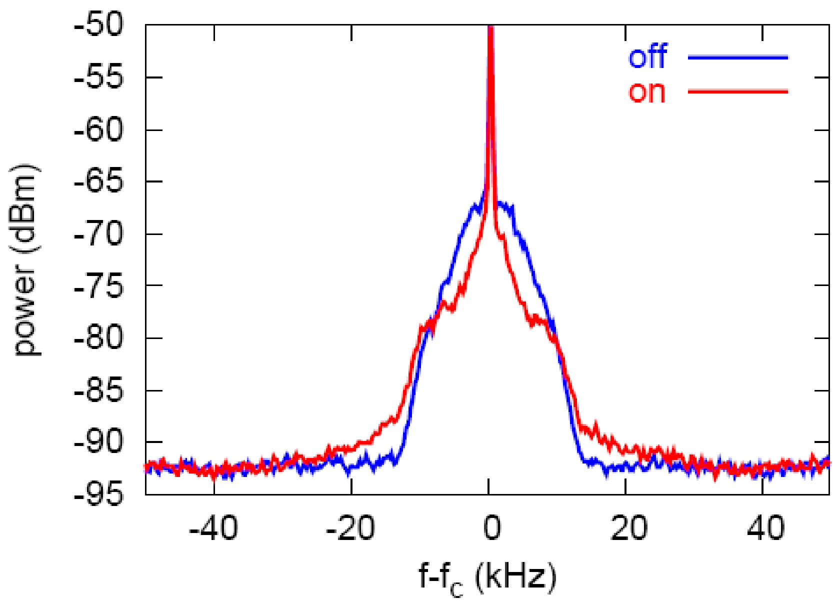
Results with protons

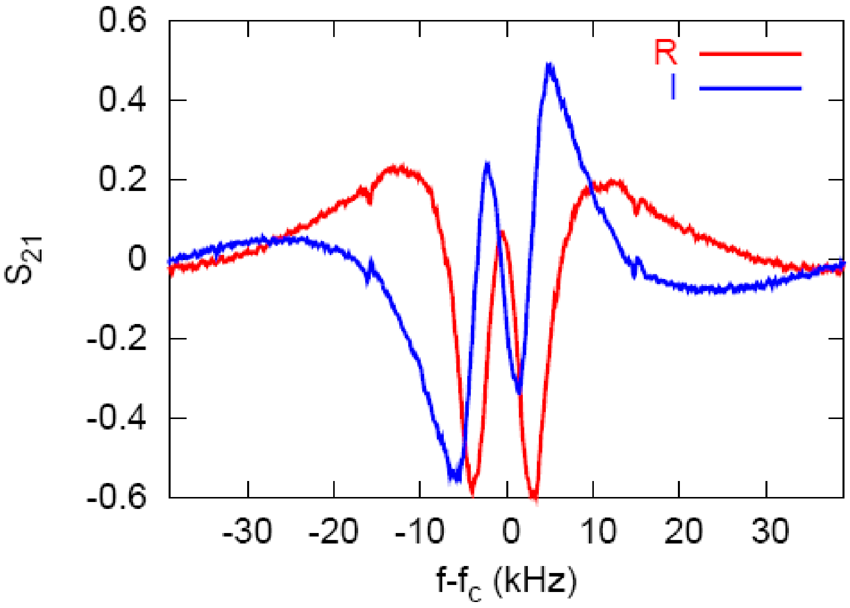
Signal suppression and

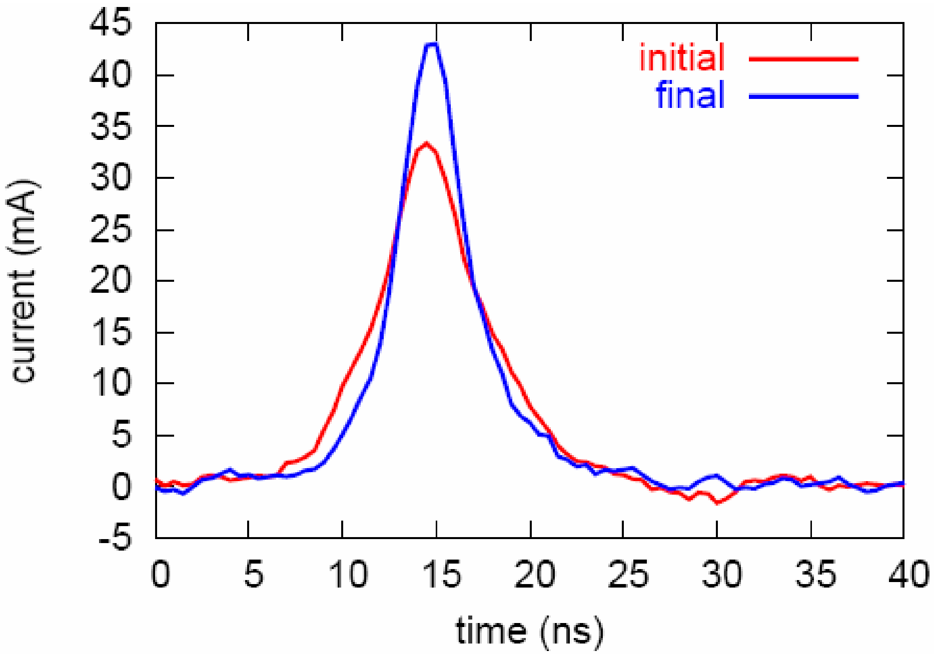
BTF at 5.2 GHz.

14 of 16 cavities operating.

Cooling achieved!







Operational scenario

- Is precooling needed? Rebucket if no.
- Check orbits, fix if needed. Close kickers and pickup (sequencer)
- Measure delay filters and correct (FEC to subordinates)
- Measure BTFs. Adjust cavity gains and phases. (same as above)
- Cool
- Periodically adjust delay, gains and phases (set interval on FEC)
- Cool
- If rebucketing not done, execute when emittance is small enough
- For blue a fast feedback loop will adjust delay due to wind and other sources of vibration.

Conclusions

Coherent signals are understood and can be dealt with.

Stochastic cooling has been demonstrated.

Cooling using narrow band cavities works.

RF voltage is constrained by the cooling system in yellow, blue should have no problems.

Automatic adjustment of cooling parameters has been checked piecewise.

Full automation looks straightforward.